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(71) Applicant: IVECO FIAT S.p.A.
Via Puglia 35
I-10156 Torino(IT)

(72) Inventor: Cuzzucoli, Giuseppe
Via Levante, 6
I-10044 Pianezza(IT)
Inventor: Genovese, Fabio
Via Parri, 5/A
I-10093 Collegno(IT)

(74) Representative: Cerbaro, Elena et al
c/o Studio Torta, Via Viotti 9
I-10121 Torino(IT)

(54) A method and apparatus for determining the clogging of a filter, in particular a filter for an exhaust system.

(57) An apparatus (1) in which a sensor (10) is provided in an exhaust duct (5) between the exhaust manifold of a diesel engine (7) and a ceramic filter (3). The sensor (10) comprises a pair of electrodes (14) which are spaced apart and which can be connected electrically by the particulate matter contained in the gas and deposited on the sensor (10). The sensor (10) also comprises an element (16) adapted to regenerate it by periodically burning the particulate matter when the conductance between the electrodes (14) exceeds a threshold value. The sensor (10) is connected to an electronic processor (12) which ensures the measurement of the number (S) of the regenerations of the sensor (10) so as to emit a clogging signal when said number (S) is equal to a previously stored limit value (S_{max}). In this way, since the number (S) of of regenerations of the sensor (10) is correlated to the number of particles flowing in the pipe (5) and thus in the filter (3), an indirect evaluation of the degree of clogging of the filter (3) is carried out.

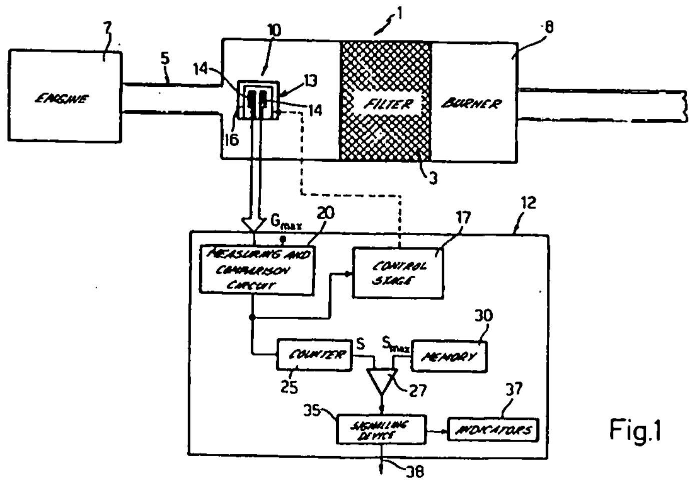

Fig.1

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In operation, the sensor 10, as already stated in the foregoing, is exposed to the exhaust gases generated by the engine 7 and the carbon particles (which are electrically conductive) are deposited on the plate 13 electrically connecting the electrodes 14.

Therefore, a conductive path is formed between the electrodes 14, the conductance of which is dependent on the particle content in the smoke and increases with time as the thickness of the deposit increases. When the conductance value exceeds the threshold value, the circuit 20 energises the control stage 17 for the heating element 16, thereby regenerating the sensor 10.

The number (S) of the regenerations of the sensor 10 is directly proportional to the amount of particles flowing in the pipe 5 and, therefore, to the contamination of the ceramic filter 3, since after the exhaust gases have acted on the sensor 10 they penetrate the ceramic filter 3.

Therefore, a maximum number of regenerations of the sensor 10 is established experimentally, by way of which it is ascertained that the filter 3 is clogged and requires regeneration.

In this way, when the number of regenerations of the sensor 10 stored in the counter is equal to the maximum number of regenerations, the signalling circuit 35 indicates, by means of the indicators 37, the poor condition of the ceramic filter 3 and requests the regeneration of said filter.

For greater clarity, Figure 2 illustrates a logic block diagram of the operation of the processor 12, carrying out the present diagnostic method.

Initially a block 51 is reached, in which the value (S) of the counter 25 is set to zero, corresponding to the operation $S = 0$. The block 51 is followed by a block 53, in which it is verified whether the value (S) of the counter 25 is strictly less than the limit value (S_{max}); if this condition is not verified, the operation passes from the block 53 to a block 55, otherwise a block 57 follows, in which it is verified whether the value (G) of the conductance measured is higher than a limit value (G_{max}). If this condition is not verified the operation returns from the block 57 to the block 53, otherwise a block 59 follows which controls the regeneration of the sensor 10. The block 59 is followed by a block 63, in which the value in the memory of the counter 25 is increased by one unit, corresponding to the operation $S = S + 1$; finally, from the block 63 the operation returns to the block 53.

The block 55 ensures the actuation of the visual and/or audible warning of clogging of the filter 3 and controls the regeneration of the filter itself, and it is followed by a block 65, in which the end of filter regeneration is awaited; in the interim, a by-pass duct (not shown) is used for the exhaust from the engine; after the regeneration, the pipe 5 with the filter 3 is reconnected and the operation returns from the block 65 to the block 51.

Figure 3 illustrates a variant of the apparatus according to the invention, designated 1a,for determining the clogging of filters disposed in a pipe 5a by way of a processor 12a.

In particular, the pipe 5a comprises a first duct 80 which extends from the engine 7 to a branch point 81 at which the duct 80 is divided into three separate ducts, respectively designated 83, 85 and 87. Respective ceramic filters 95 and 96 are provided along the ducts 83 and 85, downstream of which filters the ducts 83 and 85 join together again to form a duct 93 into which the duct 87 also flows, which is a by-pass duct. Moreover, the filters 95 and 95 are provided with diesel-fuel burners 97 and 98 controlled by the processor 12a, for the elimination of the particulate matter deposited in the filters themselves. Each burner is actuated automatically when the respective filter is cut out of the exhaust circuit for the immediate regeneration of the filter itself.

Solenoid valves 99, 100 and 101 are provided along the ducts 83, 85 (upstream of the filters 95 and 96) and along the duct 87, which interrupt the flow of gas along the ducts and are controlled electrically by the processor 12a via control lines, respectively designated by the reference numerals 105, 106 and 107. The solenoid valves 99, 100 and 101 are controlled in such a way that when one is open, the others are necessarily closed.

The processor 12a is connected to the sensor 10 disposed in the duct 80 and to a second sensor 115 accommodated in the section 93.

The processor 12a is connected to peripheral devices (suitably accommodated in a dashboard (not shown) of a vehicle), comprising an analog clogging indicator 109, indicators 37, a system RESET button 111 and a button 112 for testing the warning lights 37.

The mode of operation of the sensors 10 and 115 is identical to that described with reference to Figure 1; in fact, they can be periodically regenerated, as described above. In particular, the sensor 10 effects an indirect evaluation of the degree of contamination of the filter 95 or 96 operative at that moment, in view of the fact that the number (S) of regenerations of the sensor 10 is correlated to the number of particles flowing in the duct 80.

During this measurement cycle, the gradual contamination of the filter is displayed on a gauge 109 provided with a pointer 113 which moves on a graduated scale 114 each time the sensor 10 is regenerated, thereby providing a visual indication of the state of clogging of the particular filter operative at that moment.

During this measurement phase, the solenoid valve 101 is always closed and only one of the two

solenoid valves 99 and 100 is open (for example, the solenoid valve 99), corresponding to the filter of which the state of clogging is being determined (for example, the filter 95).

When the number of cycles (S) for regeneration of the sensor 10 equals the predetermined limit number (S_{max}),the processor 12a provides, via the indicators 37, a signal in respect of a clogged filter; additionally, the processor 12a effects the switching over of the solenoid valves 99 and 100 so as to cut out the clogged filter (for example, 95) and to convey the exhaust gases into the other filter (for example, the filter 96). Additionally, the processor 12a controls the regeneration,by oxidation,of the filter which has just been cut out (in the example in question, the filter 95).

The above-described measuring operations are repeated for the filter 96 until the processor 12a detects that this filter too is clogged. At this point, the processor 12a closes the solenoid valve 100, reopens the solenoid valve 99 (reconnecting the filter 95) and controls the regeneration of the filter 96.

The sensor 115, however, has an auxiliary function to verify the correct operation of the sensor 10 and of the filters 95, 96.

In fact, the predetermined limit number (K_{max}) for regeneration of the sensor 115 is chosen so that, under correct operating conditions of the sensor 10, this limit can be reached only after the sensor 10 has attained its own predetermined limit number (S_{max}) for regeneration. On the other hand, the counter for the regenerations of the sensor 115 is reset to zero each time the sensor 10 has undergone a number of regenerations which is equal to the previously stored limit value (S_{max}). Consequently, under normal operating conditions, the counter for the regenerations of the sensor 115 is reset to zero before reaching the predetermined limit value.

In this way, exceeding the threshold of regenerations of the sensor 115 is an indication of a fault in the sensor 10 which, evidently, is no longer able to monitor the clogging of the filters 95 and 96. Accordingly, the processor 12a controls the closing of the solenoid valves 99 and 100 and the opening of the solenoid valve 101, and supplies, by means of the indicators 37, a fault signal. In practice, the ratio between the number of regenerations of the sensor 10 and the number of regenerations of the sensor 115 is monitored; if this ratio varies beyond a predetermined limit, this is indicative of faulty operation of the sensors or filter operative at that time (split filter).

A further diagnosis of the state of the filters is provided by monitoring the pressure prevailing in the duct 80 by means of a sensor 270 disposed in the proximity of the sensor 10, which is read at the instants following the switching of the solenoid valves 99 and 100 so as to verify that the regeneration of the filter just cut in, effected at the end of the preceding operating period, has been successfully carried out.

If, at these times, the pressure exceeds a predetermined limit value, which is indicative of clogging of the filter 95 or 96, even though regeneration thereof has been attempted, the processor 12a induces the opening of the solenoid valve 101, the closing of the solenoid valves 99, 100 and the generation of a specific fault signal.

The processor 12a also effects a calculation of the rate of regeneration of the sensor 10, i.e. the number of regenerations (S) of the sensor 10 in one unit of time, so as to obtain an indication in respect of the smokiness of the engine.

The rate at which the regenerations of the sensor 10 follow one another is, in fact, directly proportional to the amount of particulate matter present in a unit volume of exhaust gas, and high values of this rate, which are indicative of malfunction of the engine, are duly signalled.

The mode of operation of the processor 12a will be described with reference to the logic block diagram in Figure 4, in which (S) and (G) indicate respectively the number of regenerations of the sensor 10 and the conductance measured at its ends, and (K) and (L) indicate respectively the number of regenerations and the conductance measured at the ends of the sensor 115.

Initially a block 200 is reached, in which (S) and (K) are set to zero, corresponding to the operation $S = K = O$.

The block 200 is followed by a block 205, in which it is verified whether the value (L) of the conductance measured at the ends of the sensor 115 exceeds a threshold value (L_{max}); if this condition is not verified by the block 205 the operation passes to a block 210, otherwise a block 206 follows, in which the regeneration of the sensor 115 is actuated and the variable K is increased by one unit, corresponding to the operation $K = K + 1$. The block 206 is followed by a block 207, in which it is verified whether the number K of regenerations of the sensor 115 is lower than a previously stored limit number (K_{max}); if this condition is verified, the operation passes to the block 210, otherwise it passes to a block 233 which actuates the closing of the solenoid valves 99 and 100 and the opening of the solenoid valve 101, so as to cut out the filters in use until that time and to convey the exhaust gases into the by-pass duct 87.

Additionally, the block 233 ensures the signalling of a malfunction condition. This condition remains until the operator presses a reset button (block 235), after which the operation returns from the block 235 to the block 200.

In the block 210 it is verified whether the value (G) of the conductance measured at the ends of the sensor 10 exceeds the threshold value (G_{max}); if this condition is not verified by the block 210 the operation returns to the block 205, otherwise the operation passes to a block 240 in which the regeneration of the sensor 10 is actuated, and the variable S is increased by one unit, corresponding to the operation S = S + 1.

The block 240 is followed by a block 242 in which the rate of regeneration V_r of the sensor 10 is calculated, i.e. the number of regenerations (S) of the sensor 10 in one unit of time. If this rate V_r is higher than a stored limit value V_m (indicative of a high level of smoke in the exhaust gases as a result of faulty operation of the engine), the operation passes from the block 242 to a block 243 in which the signalling of a malfunction is effected (for example, by the illumination of a warning light), otherwise the operation passes from the block 242 to a block 245. From the block 243 the operation passes to the block 245, in which it is verified whether the value (S), corresponding to the number of regenerations of the sensor 10, exceeds the threshold value (S_{max}); if this condition is not verified, the operation returns from the block 245 to the block 205, otherwise the operation passes to a block 230, in which the switching over of the solenoid valves 99 and 100 is effected so as to cut out the filter previously in use and to cut in the other filter.

The block 230 is followed by a block 250, in which it is verified whether the pressure measured by the sensor 270 after the switching over of the solenoid valves exceeds a previously stored limit value; in the affirmative, the operation passes from the block 250 to the block 233 which controls the closing of the solenoid valves 99 and 100, and the opening of the solenoid valve 101, so that the filters 95 and 96 are cut off from the exhaust pipe 5a and the gases generated by the engine 7 flow directly from the engine 7 to the silencer. The signalling of a malfunction is effected in said block 233 by means of the indicators 37. In the negative, however, the block 250 is followed by a block 260, which the content of the variables S and K is set to zero; finally, from the block 260 the operation returns to the block 205.

Finally, it is evident that the present invention could undergo various modifications, without thereby departing from the scope of protection of the invention.

It is evident from the foregoing how the apparatus described enables the state of contamination of the filter to be continuously monitored and makes possible the automatic switching-over of the filter, when it has reached a clogging limit value, and the subsequent regeneration thereof.

Moreover, when all the filters available are clogged or defective, during the operation of the vehicle, the apparatus cuts them off from the exhaust circuit, thereby preventing them from being permanently damaged, and provides an indication of this condition.

Claims

1. A method for determining the clogging of a filter (3, 95, 96) disposed along a pipe (5, 5a) through which flows a gas containing particulate matter, characterised by comprising the stages of: allowing a predetermined amount of particulate matter to be deposited on a smoke detector (10) disposed along the pipe (5, 5a); regenerating the sensor (10) so as to bring it into an initial state in which it is substantially devoid of particulate matter; repeating said stages of allowing the particulate matter to be deposited and regenerating the sensor (10) a predetermined number of times, and generating a clogging signal.

2. A method according to claim 1, characterised in that said stage of allowing a predetermined amount of particulate matter to be deposited comprises the stage of measuring the conductance present between a pair of electrodes (14) of said sensor (10), which are connected electrically by the particulate matter deposited on said sensor (10), and generating an accumulation signal when the conductivity measured attains a predetermined value; and in that said stage of regenerating said sensor (10) comprises the stage of bringing said sensor (10) to a predetermined temperature so as to burn said particulate matter deposited.

3. A method according to claim 1 or 2, characterised in that after said stage of generating a clogging signal, a stage of cutting out and regenerating said filter (95, 96) is carried out.

4. A method according to any one of the preceding claims, for a pair of filters (95, 96) disposed along two ducts (83,85) extending parallel to one another, characterised by comprising the stages of: cutting in a first filter (95, 96), determining the clogging of said first filter (95, 96), cutting out and regenerating said first filter (95, 96) when said first filter has reached a predetermined clogging level, cutting in a second filter (96, 95), determining the clogging of said second filter (96, 95), cutting out and regenerating said second filter (96, 95) when said second filter has reached a predetermined clogging level, and periodically repeating said

stages.

5. A method according to any one of the preceding claims, characterised by comprising the following stages: determining the clogging of the filter by means of said sensor (10) disposed upstream of said filter (95, 96); determining the residual level of smoke in said duct by means of a second smoke detector (115) disposed downstream of said filter (95, 96); setting to zero the residual level of smoke measured by said second sensor (115) in the presence of said clogging signal; generating an alarm signal when the residual level of smoke measured by said second sensor attains a predetermined admissible maximum value.

6. A method according to claim 5, characterised in that said stage of determining the residual smokiness comprises the stages of: allowing a predetermined amount of particulate matter to be deposited on said second sensor (115); regenerating said second sensor (115) so as to bring it into a state in which it is substantially devoid of particulate matter; repeating said stages of allowing the particulate matter to be deposited and of regenerating said sensor; storing the number of regenerations; and in that said stage of generating an alarm signal comprises the stages of comparing the number of regenerations stored with an admissible maximum number of regenerations.

7. A method according to any one of claims 3 to 6, characterised in that, after said stage of cutting out and regenerating said filter, the stages are carried out of measuring the pressure upstream of said filter, generating a fault signal and bringing a by-pass path into operation when the pressure exceeds a predetermined value.

8. A method according to any one of the preceding claims, characterised by comprising the stages of: calculating the rate of regeneration-(V_r)of said sensor (10); comparing said rate (V_r)with a stored limit value(V_m); generating an alarm signal when said rate of regeneration (V_r)exceeds said limit value(V_m).

9. An apparatus for determining the clogging of a filter element (3, 95, 96) disposed in a pipe (5, 5a) in which a gas flows, characterised by comprising: at least one sensor (10) which can be exposed to said gas so as to detect the amount of particulate matter deposited on the sensor (10) itself, regenerating means (16) adapted to bring said sensor (10) periodically into an initial state in which it is substantially devoid of particulate matter; monitoring means (20, 12a) adapted to actuate said regenerating means (16) when the amount of particulate matter deposited on said sensor (10) reaches a predetermined value; means for detecting clogging adapted to emit a clogged filter signal when said sensor has been regenerated a predetermined number of times.

10. An apparatus according to claim 9, characterised in that said means (25, 27, 37) for detecting clogging comprise counter means (25) co-operating with said control means (20) to count the number (S) of said regenerations; comparison means (27) adapted to compare said number (S) with a predetermined limit value (S_{max}), and means (37) for displaying said signal.

11. An apparatus according to either of claims 9 or 10, characterised in that said pipe (5, 5a) comprises an exhaust duct of an engine (7), particularly a diesel engine.

12. An apparatus according to claim 11, characterised in that said exhaust pipe (5a) comprises a branch (81) which splits into at least two paths (83,85,87); at least one of said paths conveying said exhaust gasto a filter element (95, 96); said apparatus also comprising selector means (99, 100, 101) adapted to select alternately said paths (83, 85, 87); said selector means being actuated when said apparatus (1) emits said clogged filter signal.

13. An apparatus according to claim 12, characterised in that said exhaust pipe (5a) comprises a third path, a first path (83) and a second path (85) conveying said exhaust gas respectively to a first filter and a second filter (95, 96); said selector means (99, 100, 101) being adapted to convey said exhaust gas in one of said paths (83, 85, 87) and cut off the other paths; said apparatus (1) actuating said first selector means (99, 100, 101) so as to cut in said first and second filters (95, 96) alternately when said apparatus (1) emits said clogged filter signal.

14. An apparatus according to claim 13, characterised in that said selector means (99, 100, 101) convey said gases in said third path (87) when a fault signal is emitted.

15. An apparatus according to any one of claims 9 to 14, characterised by comprising at least one auxiliary sensor (115) disposed along said duct

(5a) downstream of said sensor (10) and of said filter element (95, 96), and adapted to be exposed to the gas to determine the residual level of smoke of said particulate matter deposited on said auxiliary sensor.

16. An apparatus according to claim 15, characterised by comprising regenerating means adapted to bring said auxiliary sensor (115) periodically into an initial state in which it is substantially devoid of particulate matter; control means (206) adapted to actuate said regenerator means when the amount of particulate matter deposited on said sensor (115) reaches a predetermined value; counter means (207) adapted to count the number (K) of said regenerations and to emit a fault signal when said number (K) exceeds a limit value, and resetting means adapted to set to zero the number (K) of said regenerations in the presence of said clogged filter signal.

17. An apparatus according to any one of claims 9 to 16, characterised by comprising pressure-sensing means (270) disposed along said duct (5a) upstream of said sensor (10) and of said filter element (95, 96) for sensing the pressure of said gas conveyed in said duct (5a), and means adapted to generate a fault signal (233) when the pressure sensed exceeds a predetermined threshold.

18. An apparatus according to any one of claims 9 to 17, characterised by comprising means (242) adapted to calculate the rate of regeneration (V_r) of said sensor (10); means (242) adapted to compare said rate (V_r) with a stored limit value (V_m); and means (243) adapted to generate an alarm signal if said regeneration rate (V_r) exceeds said limit value (V_m).

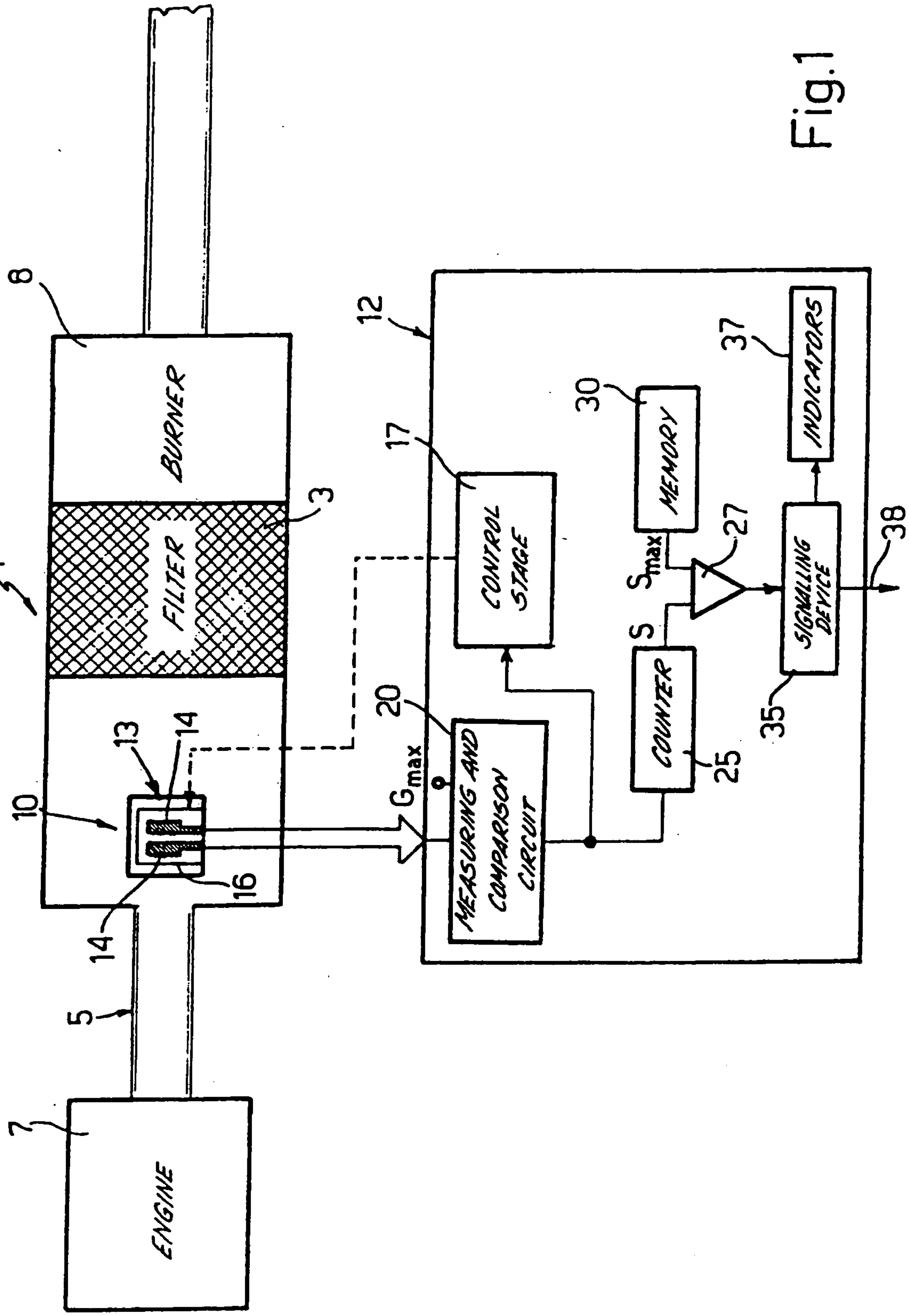
ENGINE
FILTER
BURNER
MEASURING AND COMPARISON CIRCUIT
CONTROL STAGE
COUNTER
MEMORY
SIGNALLING DEVICE
INDICATORS
Gmax
S
Smax
1
3
5
7
8
10
12
13
14
14
16
17
20
25
27
30
35
37
38

Fig.1

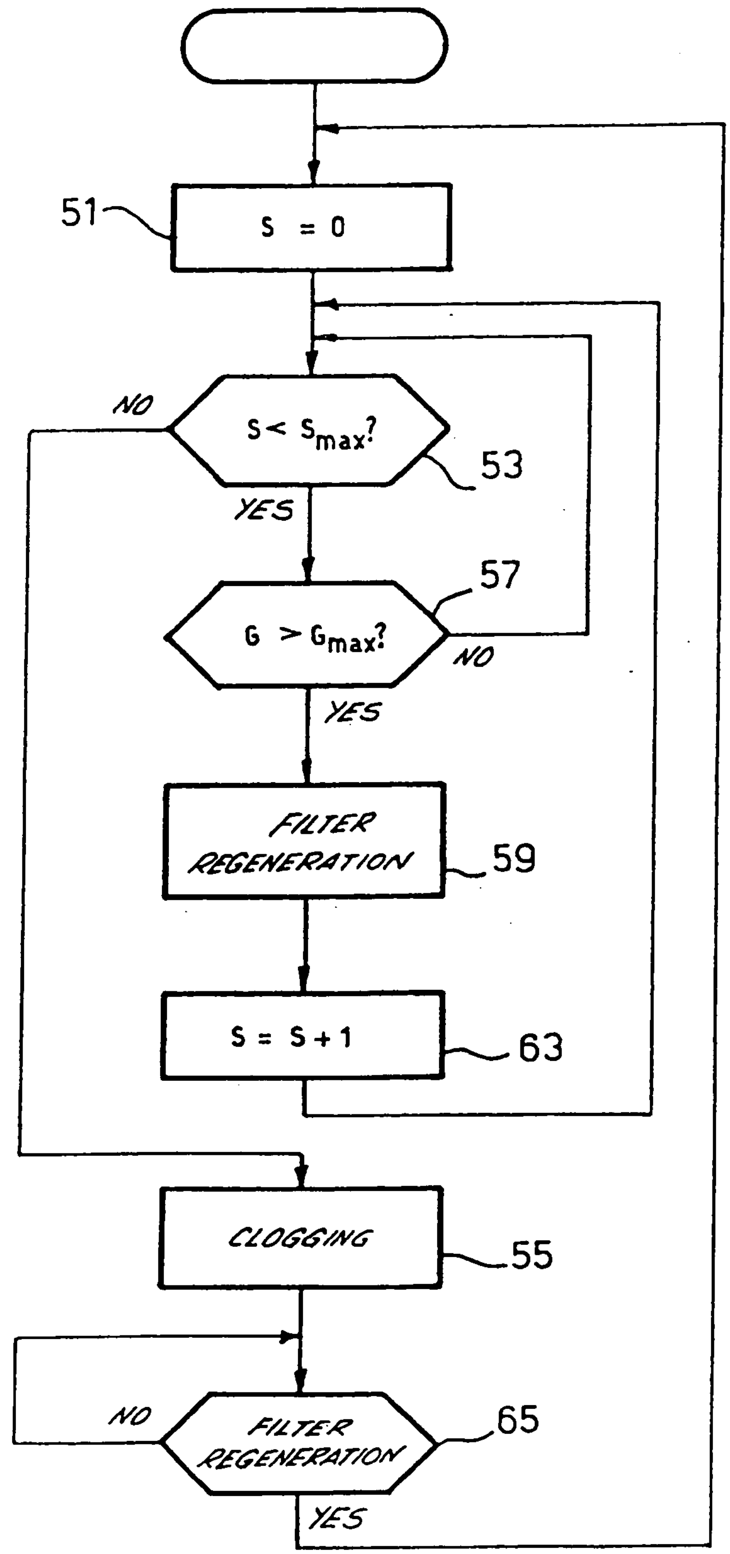
51
S = 0
NO
S< Smax?
53
YES
57
G > Gmax?
NO
YES
FILTER
REGENERATION
59
S = S+1
63
CLOGGING
55
NO
FILTER
REGENERATION
65
YES

Fig. 2

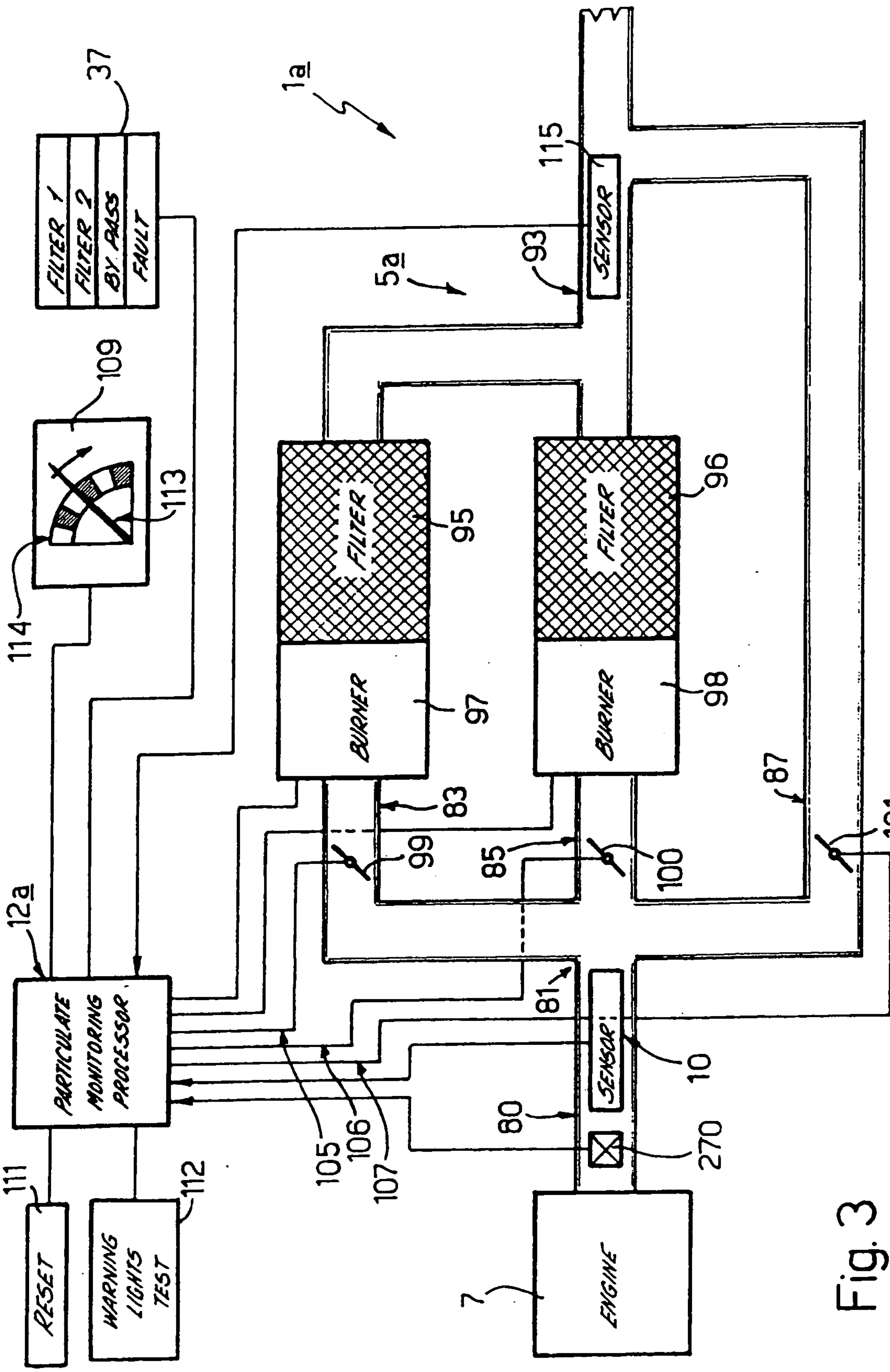
1a
5a
FILTER 1
FILTER 2
BY PASS
FAULT
37
109
113
114
FILTER
BURNER
FILTER
BURNER
95
96
97
98
SENSOR
SENSOR
115
93
83
85
87
99
100
101
81
80
10
270
PARTICULATE MONITORING PROCESSOR
12a
105
106
107
RESET
WARNING LIGHTS TEST
111
112
ENGINE
7

Fig. 3

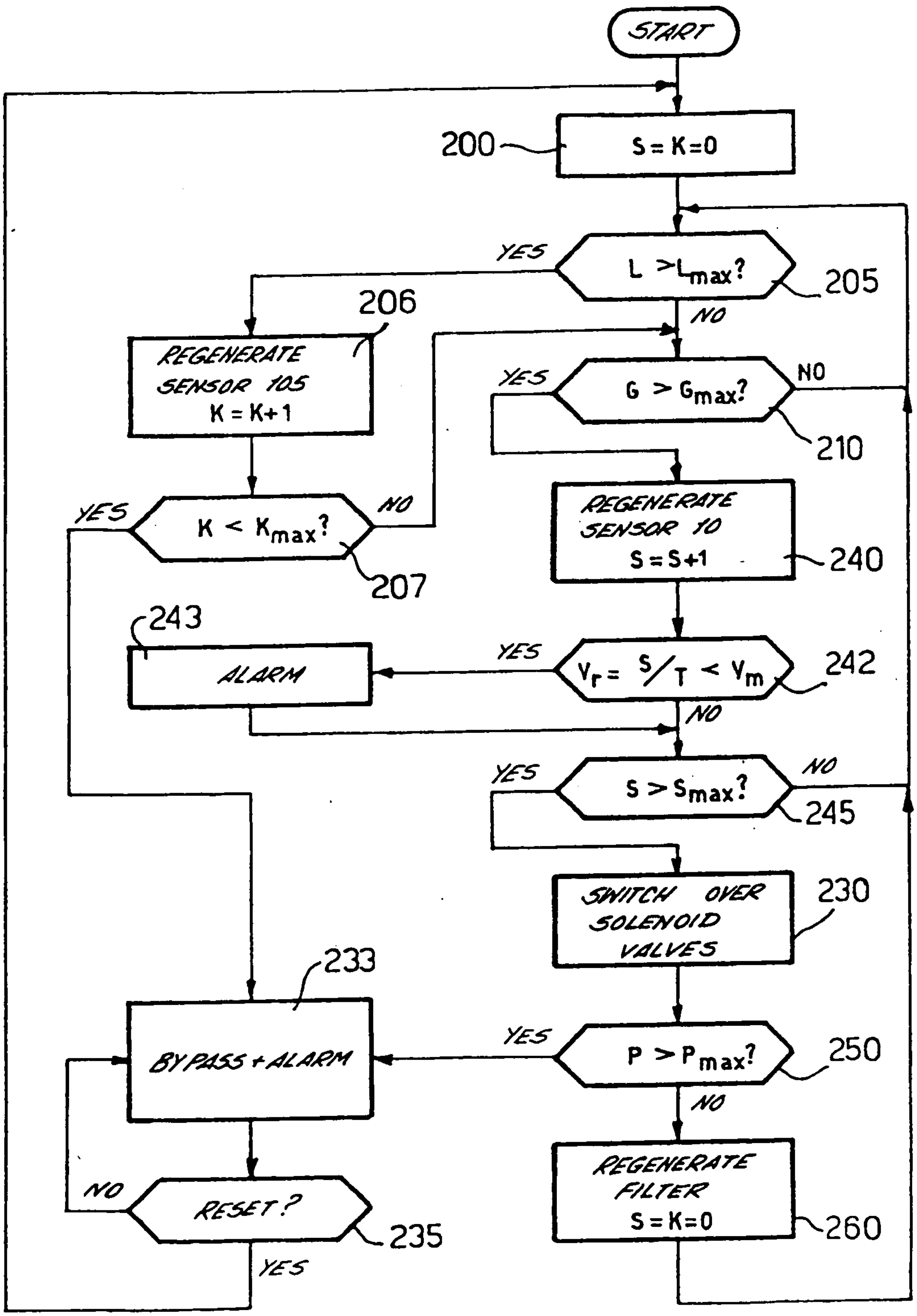
START
S = K=0
200
L > Lmax?
205
YES
NO
REGENERATE SENSOR 105 K = K+1
206
K < Kmax?
207
YES
NO
G > Gmax?
210
YES
NO
REGENERATE SENSOR 10 S = S+1
240
Vr = S/T < Vm
242
YES
NO
ALARM
243
S > Smax?
245
YES
NO
SWITCH OVER SOLENOID VALVES
230
P > Pmax?
250
YES
NO
BYPASS + ALARM
233
RESET?
235
NO
YES
REGENERATE FILTER S = K=0
260

Fig.4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 11 2347

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	US-A-4 656 832 (YUKIHISA) * column 1, line 21 - column 2, line 51 * * column 5, line 59 - column 12, line 19; figures * ---	1-3,9, 11,12	F01N7/00 F01N3/02 G01N27/04
Y	US-A-4 445 326 (LYON) * column 2, line 63 - column 4, line 50 * * column 5, line 42 - column 7, line 64; figures 1,3 * ---	1-3,9, 11,12	
Y A	US-A-4 450 682 (SATO) * column 3, line 14 - column 5, line 41 * * abstract; figure 2 * ---	3,12 7,17	
A	DE-A-3 717 141 (WEBASTO AG FAHRZEUGTECHNIK) * column 4, line 58 - column 6, line 25; figure 1 * ---	4,7, 11-13	
A	EP-A-0 237 824 (FEV MOTORENTECHNIK GMBH) * column 3, line 30 - column 4, line 53 * * abstract; figures 1-4 * -----	1,2,9	TECHNICAL FIELDS SEARCHED (Int. Cl.5) F01N G01N F02B

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	01 SEPTEMBER 1992	R.A.P. BOSMA

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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